
**Understanding Decadal Variations in the
North Atlantic Oscillation**

Duration: Two years

Total Support Requested: \$174,000
(NOAA-CDC : \$108,000)
(NCAR : \$ 66,000)

Requested Starting Date: July 1, 2000

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ABSTRACT

This project proposes, and seeks to test, the hypothesis that low frequency climate variations over the North Atlantic have a tropical origin. The investigation is motivated by emerging evidence that the North Atlantic Oscillation pattern, in particular its decadal variations during the last half century, may be consistent with similar temporal variations in tropical SSTs. A suite of atmospheric general circulation model (AGCM) experiments will be analyzed, using realistic observed and idealized SSTs, to determine those aspects of the tropical SSTs that are important for North Atlantic variability. These experiments will be further analyzed using dynamical models to determine the mechanisms that may be responsible for an atmospheric teleconnection pattern linking the tropics with the mid-high latitude North Atlantic.

A second focus is to test the hypothesis that extratropical air-sea interactions are important for decadal NAO variations. Central to this theory is that the atmosphere respond strongly to extratropical SST forcing. We will analyze the response to North Atlantic SSTs using ensembles of five different AGCMs in order to quantify the amplitude and assess the robustness of such a response. Coupled model simulations will also be analyzed in order to determine the effect of two-way midlatitude air-sea interactions on low frequency NAO variability.

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| Total proposed budget: | \$174,000 (NOAA-CDC: \$108,000) (NCAR : \$ 66,000) |
| Budget period: | Two year, starting July 1, 2000 |

1. Background

Our primary goal is to understand the origin of decadal variations in atmospheric circulation patterns over the North Atlantic. The most prominent of these is the North Atlantic Oscillation (NAO) whose time series shows decadal variations including a trend from a negative (blocked North Atlantic flow) phase in the 1950s and '60s to a positive (zonal North Atlantic flow) phase in the 1970s to mid-90s. We will develop and test hypotheses on the origin of low frequency variations of the NAO. A focus of our project will be on tropical ocean forcing of North Atlantic climate variability, and we will compare the efficacy of this potential remote factor against the effect of local extratropical air-sea interactions.

Several studies have rekindled interest in the origin of interannual-to-decadal variations in the North Atlantic Oscillation. Hurrell (1995) showed the tendency for the NAO to reside in one extreme phase since 1980, a behavior that has significantly impacted the pattern of Northern Hemisphere temperature change during the past quarter century (Wallace et al. 1995; Hurrell 1996). The one-year autocorrelation of the wintertime NAO has also achieved unprecedented high values during this recent period. Figure 1, from Hurrell and van Loon (1997), illustrates the non-stationarity in NAO during the past 130 yrs. Indeed, it is this year-to-year recurrence of a single NAO phase that accounts for the recent finding of skillful winter-season predictability across northern Europe and Scandinavia based on results of an empirical model trained on the last half century of climate data (Johansson et al. 1998).

One can argue that the above evidence for non-stationarity in the NAO time series is purely anecdotal in so far as the decadal variations are consistent with the finite sampling of an otherwise random process (e.g., Wunsch 1999). Yet, recent GCM simulations have reproduced the low frequency variations of the NAO. The model results of Rodwell et al. (1999) are provocative in this regard, and their simulated NAO correlates at 0.7 with its observed counterpart when low-pass filtered. Similar results have been reported using the NASA GCM (Mehta et al. 1999), and our own preliminary study reported further in section 2 also finds such fidelity in CCM3 simulations.

Understanding the cause for the low frequency NAO variations, in nature and in the models, has direct implications for assessing North Atlantic climate predictability. The fact that ensemble averaged GCM simulations retain a low frequency NAO signal indicates that the North Atlantic atmospheric circulation is at least consistent with, if not directly forced by, some aspect of the slowly varying sea surface boundary conditions. Importantly, the simulations give reason to believe that the observed low frequency NAO variations are not merely stochastic.

The model experiments leave the precise origin for the North Atlantic circulation response indeterminant, however, since they have been driven by global SSTs. Rodwell et al. reported the results from additional experiments in which their GCM was forced only by the tri-polar pattern of leading North Atlantic SST variability. These also yielded an NAO-like response, from which they concluded that air-sea interactions in the North Atlantic are of primary importance. Yet, independent experiments by R. Sutton (personal communication) suggest that the tropical Atlantic part of the tri-pole pattern is equally important, and the NAO response cannot be recovered solely from a midlatitude SST source.

The latter question is particularly relevant for predictability assessment. On the one hand, to the extent that the simulated low frequency NAO variations are synchronized with the imposed underlying midlatitude SSTs, little predictability may actually exist because the history of those SSTs reflects the flux-driven forcing of a single observed atmospheric evolution (e.g., Bretherton and Battisti 1999). Useful monthly-to-seasonal predictability may nonetheless exist because the time-scale of extratropical SSTs is considerably longer than that of the atmosphere. The atmosphere must respond strongly to North Atlantic SSTs for this to be of practical value, and on this matter considerable disagreement exists among the host of atmospheric GCM studies to date (e.g., Kushnir and Lau 1992; Kushnir and Held 1996; Lau 1997; Peng et al. 1997).

On the other hand, the prospects for predictability may be greater to the extent tropical SST anomalies are a factor in North Atlantic climate variability. On interannual time scales, ENSO is known to exert both a direct effect on Atlantic and European circulation systems (e.g., Fraedrich and Muller 1992; Palmer and Anderson 1994), and an indirect effect through an "atmospheric-bridge" process that alters tropical Atlantic SSTs (e.g., Saravanan and Chang 1999; Sutton et al. 1999). It is reasonable to question, for example, whether the preference for both a warm ENSO phase and a positive NAO phase since the 1970s is coincidental or casual. There is little observational evidence for a linear relation between the NAO and ENSO, though there is some indication from analysis of GCM simulations for a nonlinear relation between the NAO and tropical Pacific SSTs (Hannachi, 1999).

The major aim of this project is to clarify the role of global sea surface conditions in North Atlantic climate variability. Our preliminary analysis of the observational record suggests a link between the trend in the NAO and the trend toward warmer SSTs in the warm pool region since 1950. The degrees of freedom of the data are such that little statistical confidence can be given to these co-variations, though independent dynamical systems studies (e.g., Simmons et al. 1983) argue for a North Atlantic sensitivity to forcing from the west equatorial Pacific. We are motivated in our investigation by initial diagnosis of a suite of GCM simulations, using NCAR's CCM3, that are very much in the spirit of runs performed also by Rodwell et al.. As we will now show, these yield a coherent North Atlantic climate response to a tropical-wide pattern of SST change, and the spatial structure of this response projects efficiently onto the NAO-

mode of variability. We wish to further explore the physical cause for this apparent teleconnection, assess its robustness through analysis of additional GCM data including the runs of Mehta et al., and assess its role in low frequency NAO variations relative to the surmised impact of extratropical air-sea coupling.

2. Preliminary Analysis of Simulated Atlantic Climate Variability

An 18-layer T42 version of NCAR's Community Climate Model (CCM3) has been forced with the monthly evolution of global SSTs from 1950-94. We have begun analyzing output from a 12-member ensemble of such simulations. In these, each realization experiences the same SST boundary evolution, but is begun from different atmospheric initial conditions on 1 January 1950. An assessment of the mean climate of CCM3, including a description of the physics and parameterizations, appears in Hurrell et al. (1998).

Figures 2 and 3 illustrate the leading patterns of observed and simulated North Atlantic climate variability, respectively. The NAO is defined as the spatial structure function corresponding to the first EOF of 500 mb heights, and its pattern captures the well-known meridional sea-saw of mass between the midlatitude North Atlantic and the Arctic. The principal component (PC) time series have been smoothed with a 72-month running mean filter in order to emphasize the low frequency variations. Furthermore, in the case of the CCM3 simulations, the PC is based on the 12-member ensemble averaged NAO time series.

Several key points regarding Figs. 2 and 3 are worth emphasizing. First, the observed and simulated leading patterns of North Atlantic circulation variability are in close agreement, and in both cases they account for 28% of the height variance over the region. Importantly, the ensemble mean NAO time series correlates at 0.7 with the observed, similar to the level of agreement found in Rodwell et al. and Mehta et al.. Both the model and observed NAO time series are furthermore strongly correlated with the time series of the North Atlantic tri-pole pattern, raising again the question of the role played by local air-sea interactions.

We wish to analyze additional experiments employing a subset of the global SST anomalies to sort out the origin for the low frequency variations in Fig. 3. That other portions of the global ocean may be relevant for the model response is suggested by Fig. 4. Shown is the spatial pattern of SSTs regressed upon the observed and CCM3 NAO filtered time series. Whereas the largest loadings are found in the North Atlantic, both the observed and model regressions also show a coherent tropical pattern, the sense of which relates tropical-wide warming to a positive NAO phase. The possibility thus exists, at least in the model, that the low frequency variations in the NAO originate from the tropics. Under this scenario, the link between the extratropical Atlantic SSTs and the NAO could be largely diagnostic in the sense that the externally forced

NAO variations are themselves contributing to the North Atlantic SST variations. The process may be analogous to the atmospheric bridge mechanism that has been invoked for the seasonal variability of North Pacific SSTs driven by the teleconnections associated with ENSO (e.g., Alexander 1992; Lau and Nath 1996).

To support our hypothesis of a tropical source for low frequency Atlantic climate variations, we have formed a tropical SST time series that samples the region between 30N-30S. The filtered version of this, shown in the lower panel of Fig. 5, shows principally a warming trend, though decadal variations are also seen. There is considerable interest in understanding the SST trend in its own right (e.g, Knutson and Manabe 1998), but here we merely point out that the time series is quite distinct from an ENSO index, and is presumably unrelated to ENSO physics. Shown in the middle panel of Fig. 5 is the linear regression of CCM3's 500 mb height onto that filtered time series, and this is conspicuous for the localization of a height signal over the North Atlantic. Indeed, the regression projects strongly on the spatial structure of the leading EOF in Fig. 3, and suggests that the NAO is a mode of response to the low frequency variations of tropical SSTs. We wish to understand the physics for this apparent teleconnection, and particularly we seek to identify which aspects of the tropical SSTs are relevant. It is evident that the pattern is not the ENSO-mode of 500 mb height response, and it is indeed curious that the regression shows no loading over the North Pacific.

Finally, Fig. 5 also compares the CCM3 tropically-related height signal with that associated with the North Atlantic tri-pole pattern. The spatial separation between these two index regions is not complete in that the tri-pole also samples the tropical Atlantic. However, it is interesting to note that the CCM3 height regression onto this tri-pole mode (top panel) is considerably weaker than for the tropical SST index, nor is it localized to the North Atlantic region. The phase relation of this regression pattern with the NAO mode is furthermore quite modest leaving the impression that the tropics are at least as important as the North Atlantic SST in driving the model's low frequency NAO mode.

3. Research Tasks

Motivated by these suggestions of a co-variation in tropical SSTs and the NAO on low frequency time scales, we will diagnose suites of atmospheric GCM experiments to rigourously assess the nature and causes for such a link. The project's specific goals involve testing this new theory on the possible tropical origin of decadal NAO variations, and also testing alternate theories that focus on the role of midlatitude SSTs.

Our study will use a suite of atmospheric GCM experiments that involve ensemble climate simulations of the 20th Century using various prescriptions of the monthly evolving global sea surface temperatures.

Additional sensitivity experiments will be performed using idealized SST boundary conditions. In view of the known model dependency of SST responses, especially regarding midlatitude air-sea interactions, we will investigate the results from several different atmospheric GCMs. Many of the necessary simulations have been completed, and the data are available to this project. As mentioned previously, the response in the GCMs is sometimes as difficult to explain as are the observed anomalies themselves. As such, our project will also use simpler linear and nonlinear dynamical models to diagnose the GCMs in order to isolate the physics associated with a tropical ocean-North Atlantic teleconnection.

1. Test the hypothesis of a tropical SST impact on decadal NAO variability

We will diagnose ensemble atmospheric climate simulations forced with the monthly varying global SSTs that span the 20th Century. A 6-member ensemble of runs were the basis of the Rodwell et al. analysis. It is apparent, however, that such results can be highly GCM and sample dependent, and we propose to diagnose the output from at least 5 different GCMs. These runs, which are largely completed, consist of 16-member ensembles using NCAR's CCM3 and the NASA climate model (courtesy of V. Mehta and M. Suarez), and 12 member ensembles using ECHAM3, NCEP's climate forecast model, and the GFDL R30 model. The models have been executed at a nominal 3° spatial resolution, with the exception of the NASA model which was performed at roughly a 5° resolution. Each model has been subjected to identical evolutions of the global SST boundary conditions from 1950-94.

- 1.1 We first seek to establish the fidelity of the simulated North Atlantic climate in these models, with the assumption that a realistic climatology is a prerequisite for modeling the variability. The large volume of model data will allow us to provide a statistically robust assessment of the relation between tropical forcing and North Atlantic circulation. We will appraise the extent to which the models reproduce the observed decadal variability of the NAO during the 20th Century, in particular its trend in the last 40 years. We are especially interested to determine whether the trend toward tropical warming and the trend toward a positive phase of the NAO circulation seen in CCM3 also occurs in these other models.
- 1.2 We will quantify the fraction of low frequency NAO variations that are attributable to tropical forcing, akin to the signal-to-noise analysis used to study ENSO impacts on the Pacific climate. For this purpose, additional simulations will be studied that allow us to explicitly discriminate the effect of tropical SSTs alone from the influence of the global oceans as a whole. A 5-member ensemble of CCM3 simulations using only tropical SST forcing has been completed, and it is expected that additional runs will be performed. The analysis of these runs will clarify the extent

to which the low frequency NAO variability in the CCM "GOGA" runs are recoverable from the tropical SSTs alone.

- 1.3 We will assess the role of forcing from the Indo-Pacific warm pool, the ENSO region, and the tropical Atlantic separately. ENSO is known to force a characteristic PNA-mode of atmospheric response. However, a theory has been proposed that a second wave train accompanies the PNA pattern whose ray path spans the Caribbean-North Atlantic sector (Brunet and Haynes 1996). We will use the model data to test this additional hypothesis of a tropical effect on the North Atlantic. In addition, we will examine the extent to which ENSO teleconnections may have a nonlinear component, assessing particularly whether the conventional linear view of a weak or absent North Atlantic ENSO signal is deficient. We propose to conduct idealized SST anomaly experiments, using the NCAR CCM3 initially, to unravel the apparent causal link between the NAO and the tropics. One set of runs will impose SST anomalies over the Indo-Pacific warm pool region, and assess the impact of the warming trend in that region on North Atlantic climate. A second set will impose SST forcing over the tropical Atlantic only, and assess the extent to which the southern member of the Atlantic tri-pole pattern may force an NAO response.
- 1.4 The dynamics of the teleconnection relating tropical SST variability with North Atlantic climate variability will be diagnosed using a hierarchy of simple models. Baroclinic model diagnosis will be carried out with both linear steady state, and non-linear time dependent versions. We will identify the patterns of tropical rainfall anomalies that accompany the tropically related NAO signal. These will reveal the major diabatic heating anomalies involved, and will be input to the dynamical models to determine the global forced response to such heating.

2. Determine the role of local air-sea interactions in decadal NAO variations

We will diagnose the impact of North Atlantic SST anomalies on the atmospheric circulation using the aforementioned suite of GCMs. Because the experiments of Rodwell et al. included both tropical and extratropical SST anomalies, the attribution for their skillfully simulated NAO trend remains ambiguous. On a related matter, the hypothesis for a preferred decadal time scale of unstable air-sea interactions in the North Atlantic by Grotzner et al. hinges on the existence of a strong atmospheric response to extratropical SSTs. Our focus will be to determine the atmospheric signal related to North Atlantic SST forcing.

- 2.1 We seek to clarify the relationship between the observed low frequency NAO variations and a similar behavior in the leading tri-polar mode of North Atlantic SSTs. Is the NAO responding to

the extratropical Atlantic SST portion of the tripole, thereby providing support for the Grotzner et al. theory and Rodwell et al's hypothesis? Initially, we will diagnose the suite of GCM simulations forced with global SSTs. The statistical relation between the imposed North Atlantic SSTs and the GCMs' circulation will be calculated using standard regression and correlation techniques.

- 2.2 We will analyze North Atlantic climate variability using output from coupled model simulations. We recognize that the atmospheric GCMs may not provide a complete picture of North Atlantic low frequency variability. Experiments using atmospheric models coupled to a mixed layer ocean in extratropics have indicated an enhancement of the simulated low frequency variations, especially in the low troposphere (e.g., Blade 1997; Barsugli and Hartmann 1998). To the extent that coupled interactions are important, and provide additional feedback to the atmosphere, the AGCMs would understate the low frequency variability. Long coupled integrations using NCAR CSM, which consist of CCM3 and a fully dynamic ocean model, have been completed. We will calculate the power spectrum of atmospheric North Atlantic variability in these runs and compare with results using the AGCM with prescribed SSTs.
- 2.3 Additional AGCM experiments are proposed in which the temporal history of the monthly evolving SSTs produced in a coupled GCM are prescribed as the lower boundary in the AGCM. These runs are motivated by the notion of a possible inconsistency between imposing the *observed* SST time series in an atmospheric model, in so far as biases in that model could lead to an incompatibility between the imposed SST variations and the atmospheric flow variations. The coupled integrations are already completed, and involve NCAR's CSM. The SST history from that run will then be used to force CCM3. Available also to the project are a suite of GFDL coupled simulations using a mixed-layer ocean, which will allow us to assess the importance of 2-way air-sea interactions in the North Atlantic decadal variability.

4. Readiness

This proposal will leverage upon the infrastructure currently in place at the Climate Diagnostics Center (CDC) to archive and diagnose existing observational and GCM data, and carry out new dynamical model and GCM experiments proposed in section 2. Likewise, the facilities at NCAR will allow the execution and archival of additional CCM3 experiments, and also simulations with CCM4 which are expected to be available during our project's period.

The long-term climate simulations using global, observed SST proposed for analysis have been completed, and the data are archived in-house. Also, as an archive center for the NCEP/NCAR re-analysis data, the entire 1948-present data set is on-line at CDC. Expected project milestones by project year are as follows:

Year 1: Analysis of the available atmospheric GCM simulations with realistic global SST boundary conditions for 1950-present (Task 1); simple dynamical modeling to test hypotheses on the link between the tropics and the North Atlantic (Task 1), analysis of the available GCM simulations to assess the signal related to North Atlantic SST variations (Task 2); perform new idealized SST experiments with CCM3 and other available models to study the roles of the Indo-Pacific warm pool, tropical Atlantic SST, and ENSO variations (Task 1).

Year 2: Diagnosis of idealized SST anomaly experiments (Task 1); diagnostic analysis with dynamical models of the simulated North Atlantic response to tropical forcing (Task 1); analysis of CSM simulations (Task 2); perform and analyze additional CCM3 simulations forced with SSTs derived from CSM coupled runs (Task 2).

Given the large data volumes associated with the model runs, data storage and management will be an important issue in this project. The CDC in-house system for computing consists of 4 UltraSPARC 4-processor E450s (300 MHz), and 2 UltraSPARC 6-processor E4500s (400 MHz). Direct access disk space currently available is 1 Tbyte. Based on past experience, two limiting factors are disk storage and data transfer rates. We plan to increase storage capacity with a HSM system using DLT technology. System upgrades to increase computing power are planned that will also enhance data transfer rates and improve our capacity for graphical visualization.

Dr. Hoerling will be responsible for the project's overall direction, and will be involved in the design, execution, and analysis of the GCM experiments, and their analysis using linear and nonlinear dynamical models. Dr. Hurrell will also be involved in the analysis of observations and GCM simulations, including the coupled CSM data sets performed at NCAR. He will also participate in the design of new idealized SST anomaly experiments. Dr. Kumar will be involved in the analysis of GCM simulations, including new simulations using the NCEP's operational coupled ocean-atmosphere prediction system. The budget largely reflects the salary and benefits for a 1/3 Project Research Assistant at NCAR who will be involved in execution, post-processing, and managing the large volumes of CCM/CSM model data, and a 2/3 Research Assistant at CDC to assist in the analysis of the host of GCM data sets, and the execution of a suite of linear and nonlinear dynamical model experiments.

5. Results from prior NOAA/OGP funding

The research and operational activities of Dr. Kumar at NCEP's Climate Modeling Branch (CMB) are partially funded by NOAA/OGP, and supports a wide range of efforts related to seasonal-to-interannual prediction and climate variability. These activities have involved substantial collaboration with NOAA's Climate Diagnostics Center (CDC), through which joint studies on understanding and assessing atmospheric seasonal predictability have been performed. The research focus of Dr. Hoerling has been on the use of GCM and dynamical models to understand observed global interannual variability, especially related to ENSO. In a two previous research grants to the GOALS program element of the Climate and Global Change Program of NOAA/OGP title "*Feasibility of Seasonal Mean Predictions*" (M. Hoerling and P. Sardeshmukh, PIs, March 1994-February 1997), and "*Climate Response to Extreme Phases of ENSO*" (M. Hoerling and P. Sardeshmukh, PIs, March 1997-February 2000) three major themes were addressed, in many cases coordinated with NCEP research on improving predictions:

- (1) How does one decide whether one atmospheric GCM is better than another for making seasonal predictions?
- (2) To what extent are seasonal extratropical anomalies dynamically predictable given observed sea surface temperature conditions?
- (3) Is the climate system sensitive to details of the SST forcing, and thus is there predictability beyond that associated with a composite ENSO?

The criterion used to address the first question was whether a GCM could produce, on average, the observed footprint of the atmospheric response to El Niño, and Kumar et al. (1996) studied this issue using two near-identical versions of NCEP's climate forecast model, referred to as MRF8 and MRF9. Recognizing that the response to SSTs can be quite sensitive to the GCM employed, our recent studies are using several different AGCMs, as in the study of Kumar et al. (1999). Question 2 arises because, owing to the chaotic nature of the extratropical atmosphere, a GCM can predict substantially different seasonal mean anomalies for even slightly different initial conditions. Kumar and Hoerling (1995) showed that the extratropical signal associated with ENSO can be easily masked by the large internal atmospheric variability, and that predictive skill over North America will thus not be consistently high for every El Niño. Predictions for individual seasons will thus be inherently probabilistic, and a theoretical treatment of seasonal predictability appears in Kumar and Hoerling (1999). Question 3 seeks to determine whether wintertime teleconnection patterns other than the composite of Horel and Wallace (1981) exist. Results for the winter season were reported in Hoerling and Kumar (1997) and Kumar and Hoerling (1997) that suggest differences in SST forcing for individual events are evidently not important for the observed inter-El Niño differences in large-

scale circulation states. However, evidence is shown that US precipitation may be very sensitive to such modest circulation sensitivity to different El Niños. The question of linearity of the atmospheric response to SST forcing has also been studied in Hoerling et al. (1997; 1999), from which it is evident that the global signal related to ENSO's warm phase is not merely the mirror image of the signal during ENSO's cold phase.

The following is a list of refereed publications related to these NOAA/OGP projects:

- Hoerling, M. P., and A. Kumar, 1997: Why do North American climate anomalies differ from one El Niño event to another? *Geophys. Res. Lett.*, **24**, 1059-1062.
- Hoerling, M. P., A. Kumar, and M. Zhong, 1997: El Niño, La Niña, and the nonlinearity of their teleconnections. *J. Climate*, **10**, 1769-1786.
- Hoerling, M. P., and A. Kumar, 1997: Origins of extreme climate states during the 1982-83 ENSO winter. *J. Climate*, **10**, 2859-2870..
- Kumar, A., and M. P. Hoerling, 1995: Prospects and limitations of seasonal atmospheric GCM predictions. *Bull. Amer. Meteor. Soc.*, **76**, 335-345.
- Kumar, A., M. P. Hoerling, M. Ji, A. Leetmaa, and P. D. Sardeshmukh, 1996: Assessing a GCM's suitability for making seasonal predictions. *J. Climate*, **9**, 115-129.
- Kumar, A., and M. P. Hoerling, 1997: Interpretation and implications of observed inter-El Niño variability. *J. Climate*, **10**, 83-91.
- Kumar, A., and M. P. Hoerling, 1998: Annual cycle of Pacific/North American seasonal predictability associated with different phases of ENSO. *J. Climate*, **11**, 3295-3308.
- Hoerling, M. P., and A. Kumar, 1999: Understanding and Predicting Extratropical Teleconnections Related to ENSO. In "*El Niño and the Southern Oscillation: Multi-scale Variations, Global and Regional Impacts*" [eds. Diaz and Markgraf], in press.
- Kumar, A., and M. P. Hoerling, 1999: Conclusions from a thought experiment on seasonal predictability, predictions, and GCM ensembles. *Bull. Amer. Meteor. Soc.*, in press.
- Kumar, A., A. Barnston, P. Peng, M. Hoerling, L. Goddard, 1999: Changes in seasonal mean atmospheric internal variability associated with ENSO. *J. Climate*, in press.
- Hoerling, M. P., A. Kumar, and T.-Y. Xu, 1999: Robustness of the nonlinear atmospheric response to opposite phases of ENSO. *J. Climate*, in review.

6. Current and pending support

The Principal Investigators request no direct support for the proposed project. Their salaries are currently covered under funding at NOAA-CDC in the case of Dr. Hoerling, at NCEP/EMC in the case of Dr. Kumar, and at NCAR in the case of Dr. Hurrell. Salary support is requested for the equivalent of one Project Research Associate, and this support constitutes the project's principal budget item. It is expected that each PI will devote approximately 2 months per year to this project.